Estimation of muon doses at BNL boundary due to RHIC beamdump

November 15, 2012

Kin Yip

Experimental Support & Facilities Division, Collider-Accelerator Department

I. Introduction

This work is a re-calculation of what has been done by Alan Stevens in (1) related to the beamdump. The purpose is to calculate the muon doses at the BNL boundary due to protons discarded at the beamdump at 10 o'clock. The newest version of the software package MARS (2) has been used, partly because it allows me implement magnetic field in the beamline.

II. Setup

Figure 1 shows the plan view of the geometry setup (along the proton beam direction which is also the z-axis) in the MARS simulation. In the simulation, y-axis is pointing towards the sky and x-axis is the remaining lateral dimension (with its direction consistent with a right-handed coordinate system). Figure 2 provides a more detailed and magnified view of the beamdump structures.

Various components (from Q4, Q5, D5 … to D8) up to 80 m away from the beamdump are implemented in the geometry and magnetic field setup of the simulation. It is a painstaking process to put in the appropriate positions and the right magnetic fields and signs. To make sure that the magnetic field and signs are correctly set, I have tracked the trajectory of a proton inside the MARS simulation to make sure that the protons stay inside the beampipe, in the middle of the dipole and quadrupole magnets. This has turned out to be an essential check and useful debugging tactic.

The same approximation of magnetic field in the yoke/coil region of the dipoles and quadrupoles as described in the Appendix A of (1) has been used, with more update numbers in radii (R1 & R2 as mentioned in the above-mentioned Appendix A).

As one can see from Figure 1, the beamline gradually curves away from the forward direction. But we have to bear in mind that our goal is to find the muon dose at the nearest boundary which is in the forward direction. Since the RHIC tunnel (that is bending away) become less and less relevant (as we will discuss again in the results described below), we extend the tunnel up to 100 m from the beamdump in this simulation.

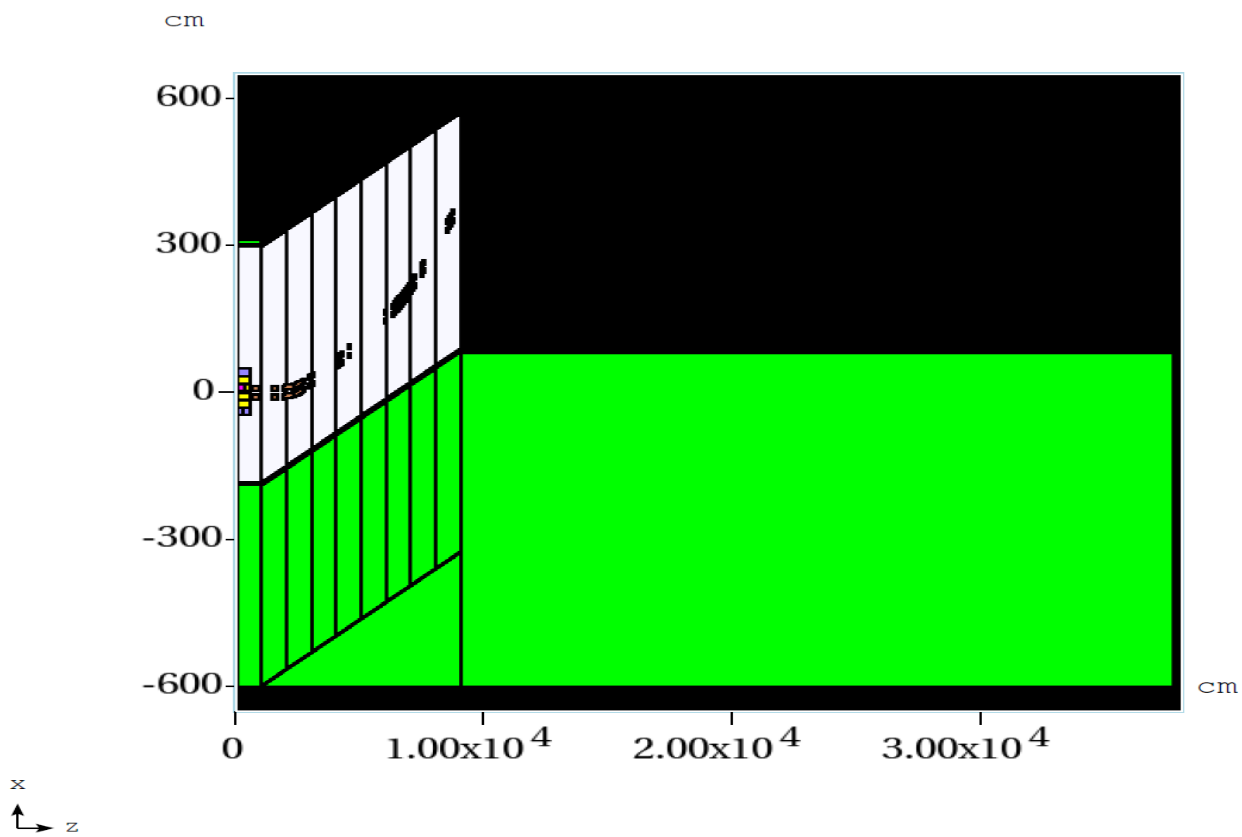


Figure 1: A picture of the beamline and the soil in MARS (green). The black line in the middle of the magnets is the trajectory of a proton which it starts from the center of the beampipe (ie. from the leftmost side of this picture).

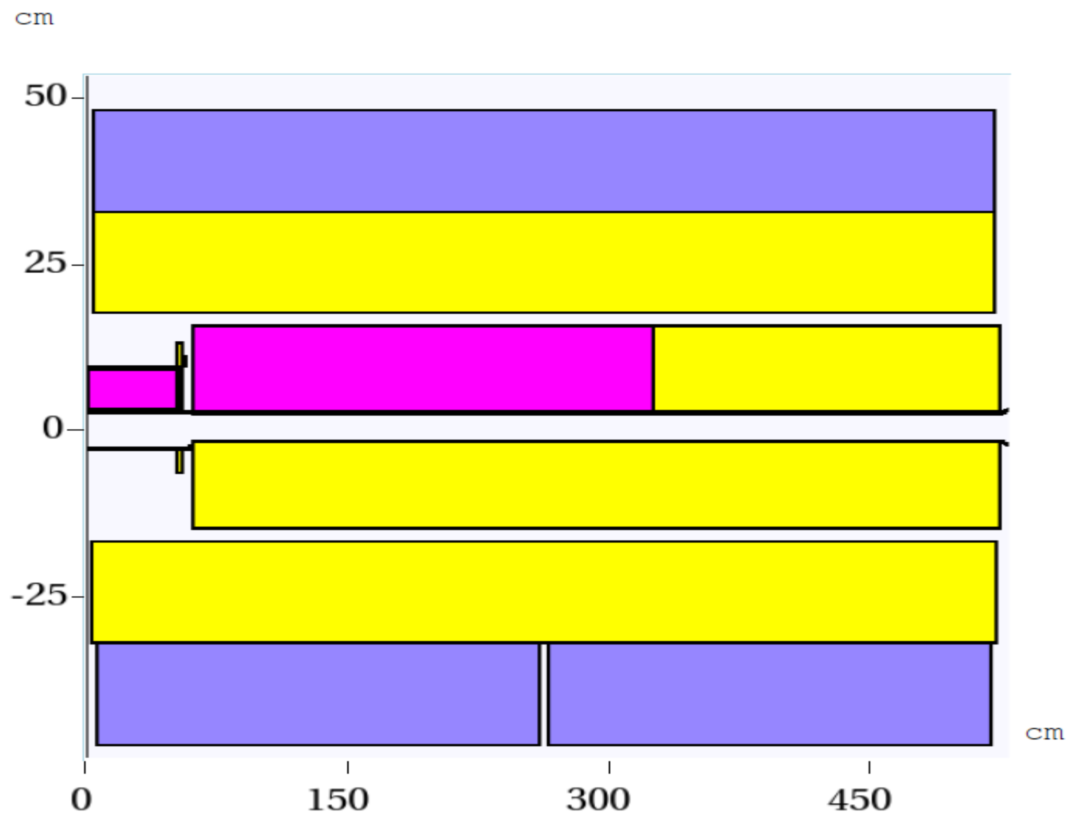


Figure 2: A XZ view of the beamdump (where Z is the original proton beam direction). The first pink block is the CC (special carbon-carbon material) and the proton beam is scanned The second pink block is the graphite. The yellow blocks are steel and the grey blue blocks are marbles.

The beam consists of protons at 250 GeV or 300 GeV with a uniform horizontal distribution of 1.95 cm (due to the kicker) in front of the CC block in Figure 2 and vertical position fixed at beam height, hitting the front surface of the beamdump. (3)

III. Results and Discussion

The beam height is about 69 feet and 2 inches above sea-level. From the map that I have obtained, I estimate by my own eyeballing that the end of soil above this height lies probably about 377 m away from the beamdump. (This is why I had extended geometry to such distance in Figure 1.) But according to (1), it is about 321 m away from the beamdump. For the reason of being conservative and convenience of comparison, I show the dose results for the latter distance (ie. doses at 321 m from the beamdump).

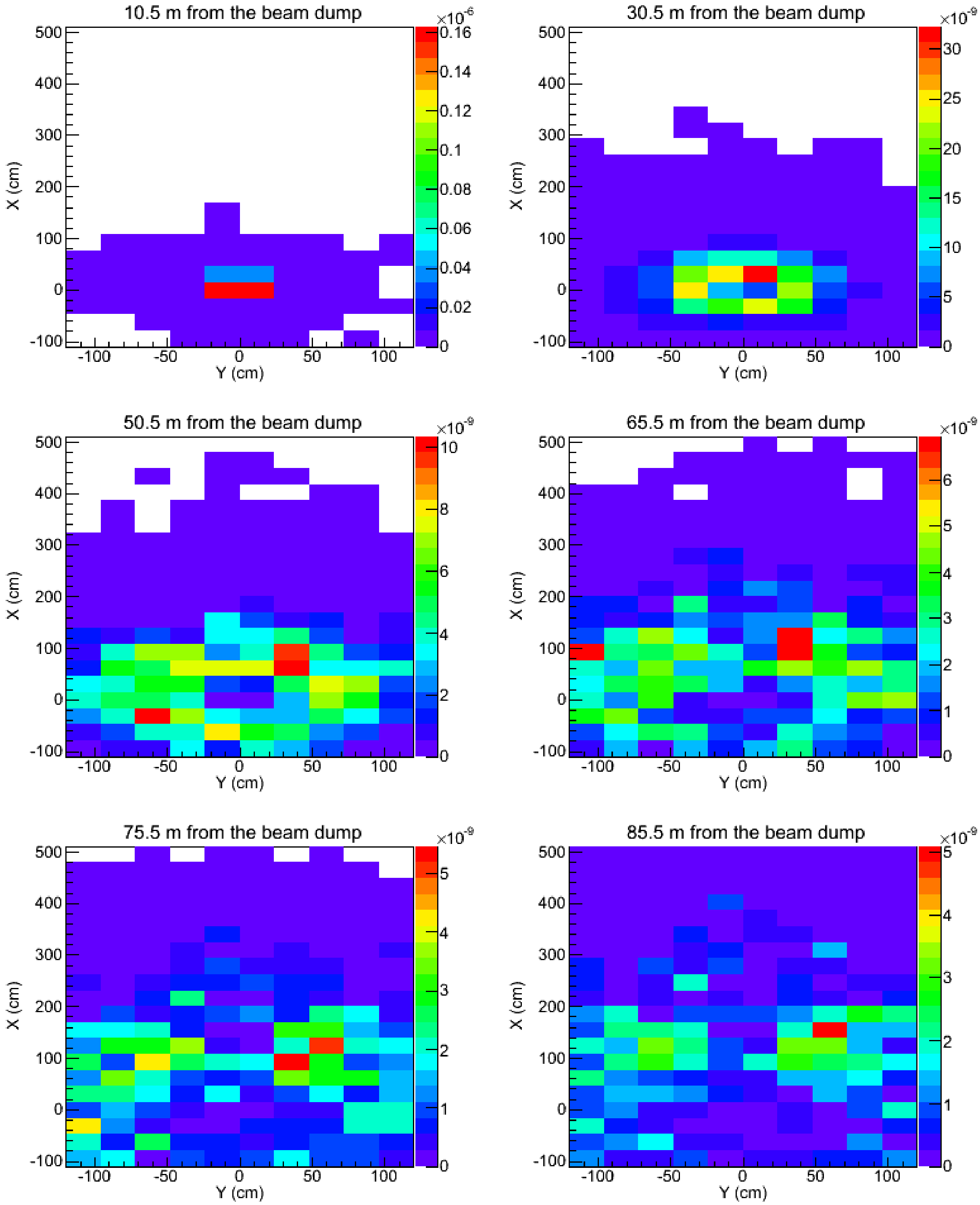


Figure 3: Transverse flux distributions of the muons in the RHIC tunnel at various distance from the beamdump. *Owing to the peculiar feature of the MARS software, the vertical axis is the x-axis (geographically horizontal) whereas the horizontal axis is the y-axis (geographical vertical).*

Even after taking a lot of CPU time (as well as real time) for the simulations, the results shown above and below all have some statistical uncertainties (at least 10%). Figure 3 shows the flux distributions of the muons in the RHIC tunnel at various distances from the beamdump. *Owing to the peculiar feature of the MARS software, in* Figure 3 *the vertical axis is the x-axis (geographically horizontal) whereas the horizontal axis is the y-axis (geographical vertical).* One can see that the maximum muon fluxes are located at larger x as the (z) distances from the beamdump increase. That is, as can be seen from Figure 1, the locations of the maximum muon fluxes follow roughly the bending of the RHIC tunnel and they are further and further away from the forward direction, which points to where the nearest BNL boundary is. As those muons in the tunnel are further and further away from the beamdump, they bend along the tunnel and become less and less relevant as far as the doses at BNL boundary is concerned. The muons that really matter are those that penetrate the soil in the forward direction in order to reach the nearest boundary in question (and give rise to doses).

Figure 4 shows the distribution of maximum doses (in mSv/hour) in the RHIC tunnel at various distances from the beamdump when there is only 1 proton per second. Figure 5 shows the distribution of maximum doses (in mSv/hour) in the soil at various distances from the beamdump when there is only 1 proton per second.

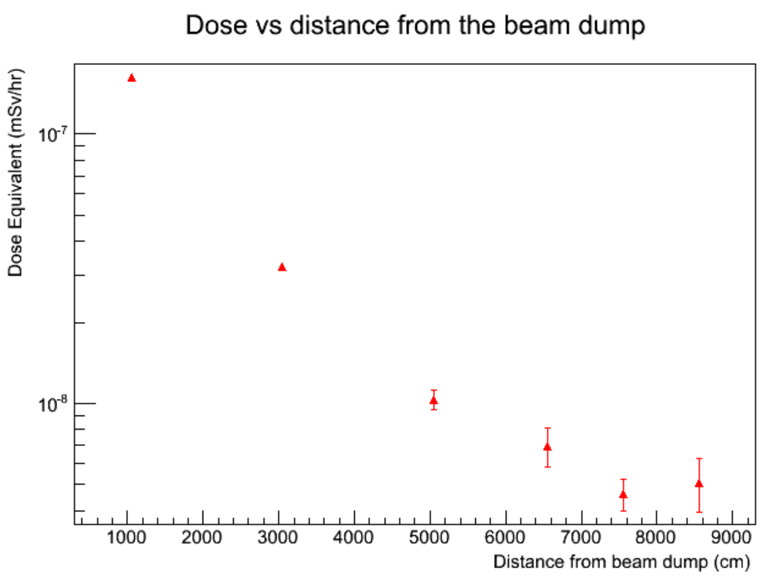


Figure 4: Distributions of maximum doses in the RHIC tunnel at various distances from the beam dump when there is only 1 proton per second.

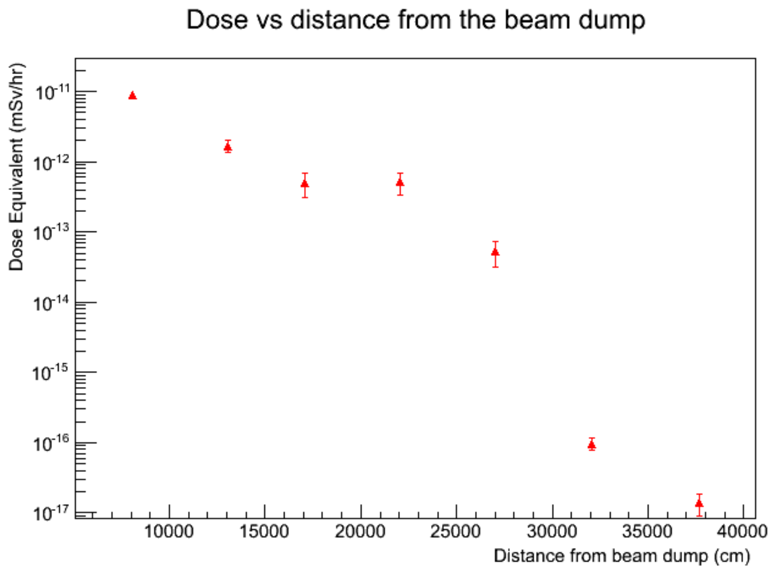
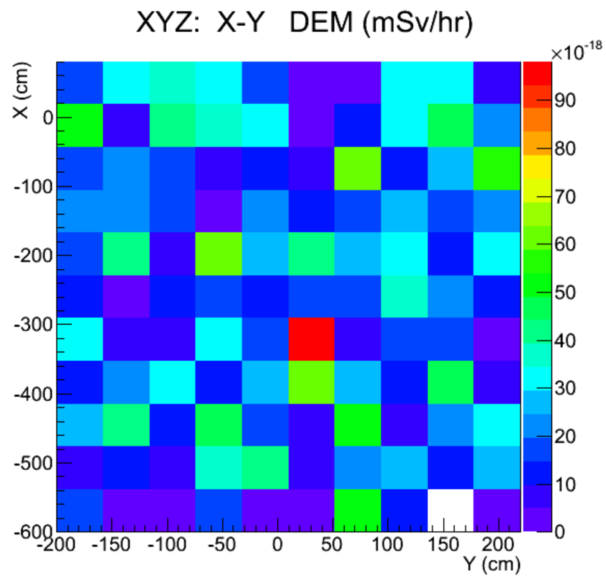


Figure 5: Distributions of maximum doses in the soil at various distances from the beam dump per proton when there is only 1 proton per second.

Figure 6 shows YX profile of the muon dose (in the unit of mSv/hour when the beam intensity is 1 proton per second, which is a MARS convention in this type of plot) at 321 m from the beamdump for the proton beam energies at 250 GeV and 300 GeV respectively. I have divided the YX plane into 10 × 10 grids.



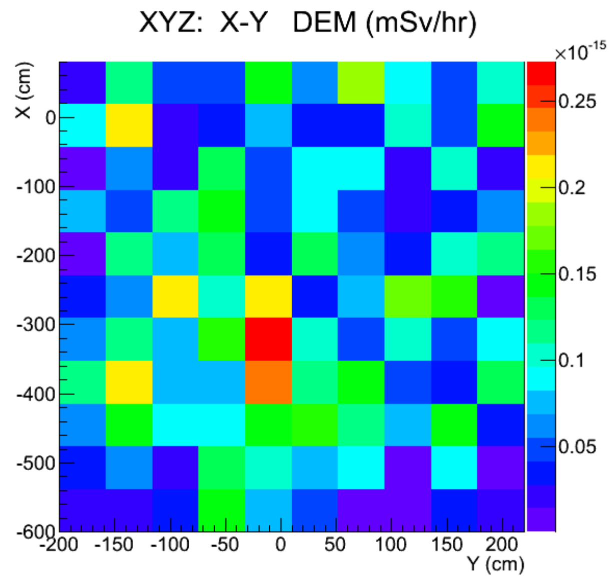


Figure 6: The YX profile of the muon doses (assuming 1 proton/s) at 321 m from the beamdump for the proton beam of 250 GeV (left) and 300 GeV (right) respectively. *Owing to the peculiar feature of the MARS software, the vertical axis is the x-axis (geographically horizontal) whereas the horizontal axis is the y-axis (geographical vertical).*

At 250 GeV, the maximum dose is found to be the $(9.8\pm 1.6)\times 10^{-17}$ mSv/hour for the rate of 1 proton/s. Assuming the proton intensity of 2.5×10^{16} protons per year, this corresponds to (0.068 ± 0.011) mrem per year.

At 300 GeV, the maximum dose is found to be the $(2.73\pm 0.42)\times 10^{-16}$ mSv/hour for the rate of 1 proton/s. Assuming the proton intensity of 2.5×10^{16} protons per year, this corresponds to (0.189 ± 0.029) mrem per year.

Again using (1), the boundary is (650-66) or 584 m away from the beamdump. $1/r^2$ gives $(321/584)^2 = 0.302$. Therefore, the muon doses at the BNL boundary are:

250 GeV : $(0.068 \pm 0.011)*0.302 = (0.021 \pm 0.003)$ mrem per year ;

300 GeV : $(0.189 \pm 0.029)*0.302 = (0.057 \pm 0.009)$ mrem per year .

IV. References

(1) AD/RHIC-46, RHIC Technical Note No. 46, "Radiation From Muons at RHIC", A. Stevens, Feb. 1, 1989.

(2) MARS, version 15, http://www-ap.fnal.gov/MARS/.

(3) Private Communication with Leif Ahrens.